

ON THE MUDDY WATER OF THE HUGLI DURING THE RAINY SEASON WITH REFERENCE TO ITS PURIFICATION AND TO THE CALCUTTA WATER SUPPLY.—By D. WALDIE, Esq.

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CONTENTS.

- I.—Introduction,—construction of the Filters at Palta, difficulties in their working—question as to the cause of this,—true cause, according to the author, is the peculiar nature of the water.
- II.—Desirableness of explaining the reason of this peculiarity,—considerations which led to its discovery,—its nature,—experimental evidence in proof.
- III.—Corroborative evidence from other sources, direct and indirect.
- IV.—Details of experiments connected with it and results.
- V.—Further corroborative evidence and additional explanatory remarks.

I.—The works for the supply of Calcutta with water have been in operation since the early part of 1870. The nature and arrangement of the filtering materials in the filtering tanks at Palta were decided upon chiefly from the results and conclusions to which I came after a series of experiments made during the rainy seasons of 1868 and 1869, for the purpose of ascertaining what was likely to be most suitable and efficacious for filtering the muddy water of the Hugli during the floods that extend from June to September or October annually. These experiments also included an examination of the value of a particular contrivance called Spencer's Regulating Cup, to which great importance was attached by the Engineer who designed the works. The general conclusions to which I came were, that this Regulating Cup possessed no *special* value, for that the retardation of the flow of water which was stated to be its particular function could be attained equally well or better by other means ; and that the better sand of the two kinds submitted to me for comparison was the fine sand from the sand-bank in the river, which, as it could be obtained on the spot, was called Palta sand. The other sand, called Magra sand from the locality at which it was found, was considerably coarser in grain, and was stated to be more like that used for filters in England. Though well enough aware of this, I decidedly preferred the Palta sand for filtering the muddy water of the rains, which was the period of special difficulty. For the remainder of the year, I considered it of little importance which kind of sand should be used.

In accordance with my recommendation, the filters were fitted up with Palta sand and without the regulating cups. They worked well during the first rainy season ; but afterwards, particularly during last season (1872), there was so much difficulty in getting water filtered through them sufficiently

clear, and in the required quantity, owing to the largely increased demand, that they were pronounced a failure by the Superintending-Engineer, who advocated a trial of the coarser sand combined with the Regulating Cup, with, as he said, assurance of success, and in the view of adapting this arrangement to the whole eight filters if found satisfactory.

No more complete condemnation of the arrangements I had recommended could well have been made. Reasons were given for it, of which I need only state the principal. The Palta sand was too fine, and consequently rapidly became choked up; such sand was not used in England. It was a principle laid down by Engineers that the muddy particles should not penetrate more than an inch or two below the surface of the sand; this was not the case here, as they penetrated deep into the sand, and made it foul throughout. The fine sand retarded the flow of water too much, and speedily became choked up by the deposition of mud; the proper retardation and regulation of the flow should be effected from below, either by a greater depth of coarser materials, or by the use of the Regulating Cup.

My replies to these reasons were that the fine sand was not too fine for the water which was to be filtered, and that if not used in England, neither was such water filtered in England. This mud of the Hugli water during the rainy season could not be prevented from penetrating deep into the sand, at least if the water were to pass at such rate as would be practically of use; that the choking up of the sand to a certain extent, instead of being an objection, was essential to its proper action as a filter for this water, and the object should be not to prevent but to regulate it,—and that it could be prevented neither by a greater thickness of coarse material nor by regulating cups. And, further, that the difficulty and consequent great amount of labour and trouble in filtering the water during the rainy season was caused, not by the particular arrangement or nature of the filtering materials but by the nature of the water itself; and, consequently, that the proposed remedy was entirely delusive, and would certainly fail.

Though no formal opposition, so far as I am aware, has ever been made to my statements or opinion respecting the quality of the water, neither has the conclusion been formally admitted as correct, and it has been overlooked or neglected in all reasoning on the subject, at least as a sufficient explanation of the difficulty. The principles of sand-filtration were appealed to, and these were explained to depend chiefly on the attractive power of the coarser particles of sand for the finer particles of the mud suspended in the water; and this was represented as the most important part of the process,—“such is, in fact, filtration,”—apparently almost to the exclusion of what was called mere straining. This explanation I hold to be totally erroneous. The most important part of the process is straining, the prevention of the passage of particles through narrow crevices between the grains of sand; next is depo-

sition by gravity, on the upper surface of these granules, of still finer particles;* and last, and least important of all, is the mutual attraction of particles of mud and sand independent of gravity. The influence of all of these processes will be affected by the greater or smaller size of the particles of mud in suspension, and the difficulty in getting the water to pass clear will be the greater the smaller the particles are. Hence the great difficulty with the water in question, the particles being so very fine.

II.—The peculiarity of the Hugli water from June to October I had always connected with the tropical rains and melting of the snows at the sources of the Ganges, occurring together so as to form one great flood of four or five months duration, instead of occasional floods to which rivers of European countries are subject, exceeding these greatly both in amount and in duration. I had not, however, been able to offer any other than conjectural explanations of its slowness in clearing by settling and of the difficulty in filtering it, of which I had found abundant evidence as a matter of fact. Attention having been again directed toward the subject by the circumstances previously referred to, I was led again to think of the advantage it would give me to be able to state some reason for my belief that the cause of difficulty lay in the nature of the water; some explanation of this peculiarity,—a reason why it should be so,—some generalisation shewing that it was not an isolated fact, but one of other similar facts admitted and acknowledged. Indeed, ever since it had been so forcibly brought under my own notice by my filtration experiments, and fixed in my own mind at least as a certainty, I had been alive to everything, old and new, that appeared to have a bearing on the subject, whether it were practicable means of purifying the water or a way of explaining the difficulty.

With respect to purifying muddy water generally there were certain methods which were well known and others less generally. The use of alum and other salts of alumina for such a purpose had long been known: salts of peroxide of iron, a substance chemically having much analogy with alumina, had more recently been introduced, and in my opinion they were even superior to salts of alumina. These substances act by the alumina or peroxide of iron being separated from its combination with the acid by alkaline matter which might be added along with them, or by the action of the carbonate of lime present in many waters, or even simply by large dilution, as in this case the base tends to separate from the acid. The alumina or oxide of iron separates in loose soft flakes which envelop or attract the fine particles of the mud, and carry them down with them, leaving the liquid quite clear. Indeed many other substances that produce flocculent precipitates by the addition of another substance have the same effect; thus by adding a solution of sulphate

* Well illustrated by Wanklyn and Chapman in the 2nd edition of their treatise on Water Analysis.

of copper, and then a little soda, oxide of copper is thrown down carrying the mud with it. I have, indeed, made use of this method for precipitating the fine, suspended mud for chemical examination; the oxide of copper being removed from the precipitate, after collection, by ammonia and acetic acid, and the mud washed. This process, when the precipitants are employed in proper quantity, is speedy and convenient.

There is another class of substances which operate in a similar way, namely, alkalies and alkaline earths, such as Soda and Lime. These combine with the carbonic acid that keeps carbonate of lime in solution, which becoming insoluble is consequently precipitated. When Lime is used an additional quantity of carbonate of lime is produced. This, in fact, is Dr. Clark's well-known process for softening such waters as owe their hardness to carbonate of lime in solution. The precipitate formed carries down other matters with it leaving the water clear. The objection to the use of this process is the large quantity of additional sediment produced, and the risk of some prejudicial effect on the quality of the water, at least if not carefully managed.

Another class of substances the mode of action of which is not so evident, is acids. I do not know when this was first noticed. Graham, Miller, and Hofmann in their Report on the London waters, June 1851, speaking of the impurities, refer to "this clay tinge which resists the action of acids." Whether from this hint or not, I do not recollect, but I myself employed acids in 1866 for the purpose of clarifying the muddy waters of the Hugli during the rains.* A small quantity of Nitric or Hydrochloric acid added to a large bottle of muddy water so altered and precipitated the mud that next day, or even in a few hours, it could be filtered clear with ease. I used alkalies, also, and perchloride of iron; but did not prosecute the subject further, my object having been simply to get the water clear with as little addition of foreign matter as possible; and nothing was better than a little of these acids,—even of acetic acid.

There is yet another class of substances the action of which is equally if not more difficult to explain, namely, those substances usually called neutral salts, both alkaline and earthy. The first direct notice I found of this was in some remarks in the 'Chemical News' of 3rd April, 1868, by Mr. W. Skey, Chemist to the Geological Survey of New Zealand, on the property of this class of substances to clarify muddy water. In this he specifies that 1 grain of common salt clarifies 5 ounces of muddy water and 1 grain of chloride of calcium or barium 10 ounces, 1 grain of lime 15 ounces and 1 grain of sulphuric acid 50 ounces. He thinks that these substances must act solely from their affinities for water, as it is not at all likely that they undergo any decomposition themselves. In the 'Chemical News' of 8th

* Journ. As. Soc. Beng., 1867, Vol. XXXVI, Pt. II, p. 7.

July, 1870, is a short abstract from the 'Comptes Rendus' of the Academy of Sciences, of 20th June 1870, of a paper by Dr. C. Schloesing on the same subject, in which, it is stated, he refers to river waters contaminated with clay being readily clarified by 1000th part of chloride of calcium or other salts of lime, and being then readily filtered, while previously they rapidly choked the filter. He refers to several rivers, such as the Rhine in its lower course and the Durance which supplies Marseilles, as being notorious for this peculiarity. Then in the same Journal of 12th May, 1871, Mr. Skey notices this as a re-discovery on the part of Schloesing, and says that 1 grain of chloride of calcium is sufficient for 10 ounces of muddy water or 50,000 grains, an evident misprint for 5000 grains. He also notices a paper on the so-called molecular movements of microscopic particles by Professor Jevons, who has some theory about this coagulation of clay being due to the water becoming by such addition a conductor of electricity, and the clay particles charged with electricity.

Besides all these direct observations, there is a phenomenon which had long (long before these observations were made) come under the observation of chemists in filtering and washing certain precipitates and sediments, namely, that for a time, while there is saline matter present in solution, the filtered liquid comes clear, but when, by continuing to wash such substances by distilled water, these saline matters become much reduced in quantity, then the filtered liquid flows muddy, the solid substance passing in a state of very fine division through the pores of the filtering paper. The chemist to avoid this adds a proportion of some saline substance (such as chloride of ammonium or muriate of ammonia) which will not interfere with his subsequent proceedings, and so is enabled to wash the sediment or precipitate free from everything except the substance which he has added. He can get rid of this afterwards by other means if it be necessary. This peculiarity especially occurs with clays and substances more or less analogous to them, such as Zirconia and Titanic acid. Another illustration is given when we attempt to extract the saline matters soluble in water from clayey soils. When the soil is first mixed with distilled water and allowed to settle, the supernatant liquor may be clear: if this be poured off and more distilled water be mixed with the residue, it will not settle and clear so readily, and if the process be repeated, it may take a very long time to do so. Just in proportion as the saline matter is removed, the fine clay separates with greater difficulty from the pure water.

It is to be observed that the substances here referred to, namely, neutral salts, are just the same sort of matter that exists in natural waters in small quantity. Reflecting on the difficulty, with the impression of the above-mentioned facts on my mind, on or about the 1st August last, the question occurred to me: How small a quantity of such substances is sufficient

so to change the character of the mud in the river water of the rains as to enable it to settle with sufficient readiness, and in such a state as to render the water capable of being filtered without difficulty? Will the difference of quantity between that of the saline matter which exists in the water of the rainy season and that, say, of December be sufficient? Will the addition of such small quantity of the same kind of saline matter that exists in the river water to the water of the rainy season, so change its character that these difficulties in settling and filtering will be removed? Without delay a few experiments were instituted and their results observed, and these results shewed that the question was solved in the affirmative and the whole difficulty cleared up. The Hugli water during the rains contains too much pure water in proportion to its saline constituents, or these natural precipitants are present in too small quantity to precipitate the mud, as they do in other localities which have no tropical rainfall to produce so great dilution. And now my previous conviction as to the cause of the peculiarity was at once confirmed and explained.*

The first experiment was made by means which came at once to hand. One quarter of a litre of muddy water from the river was mixed in a bottle with an equal volume of water from a tank which, in the dry season, I had found to contain a considerable quantity of saline constituents. Now, from the rains, I knew that it must be considerably more diluted, nevertheless not so diluted as the river water. In another bottle, for comparison, was mixed an equal quantity of the river water with the same volume of distilled water. It seemed natural to think that this mixture with distilled water would settle most speedily, more particularly as the tank water contained much glutinous vegetable matter; nevertheless, notwithstanding this disadvantage, the mixture with the tank water settled best. It was not a very good experiment, yet the result was quite distinct.

Then solutions of sodium and of calcium chloride (common salt and muriate of lime) were prepared of known strengths. The amount of saline constituents in the river water during the rainy season was pretty well known from former analyses, and these solutions were added in such quantity as approximately to double the quantity of saline constituents in the water, and thus bring it near the composition of the river water of December as regards alkaline and earthy salts. This produced an improvement in the settling, very slight in the case of common salt, very decided in that of chloride of calcium (muriate of lime). This at once shewed, what was afterwards abundantly confirmed, that lime salts were much more efficacious than alkaline salts. I shall return to this part of the subject further on.

* At the meeting of the Society on 4th August last I intimated that I had discovered what I believed to be the true explanation of the difficulty with the water. *Vide* Proceedings for August, 1873.

Another obvious-looking plan was to dry a measured portion of the water and add its solid constituents to an equal quantity of water, so as to double the total amount. But there were practical difficulties in this process, in the changes the constituents would undergo by evaporation; it was, however, done thus: a portion of filtered water from the Calcutta hydrants was concentrated by evaporation over the water-bath to one-fifth of its volume; after this carbonic acid gas was passed through the concentrated liquor in order to redissolve the carbonates of lime and magnesia which had separated. One volume of this concentrated water was now mixed with four volumes of muddy river water, so as to make up the original quantity. This mixture, on being allowed to stand, settled well and the water could be filtered easily. In all cases a similar bottle of the muddy water, unmixed with anything, was placed beside these mixed waters for comparison.

In all the above experiments the waters were allowed to stand 24 or 48 hours to settle. This was a point I had calculated on, as the object was not to clarify the waters as rapidly as possible, but to imitate the settling and clearing of other natural waters or of the Hugli water itself during the dry season, by assimilating its composition so far as regards soluble salts to that of those.

III.—I have examined the tables given in Bischoff's *Chemical Geology** of the composition of various river waters for anything to be found bearing on this subject, and the author's remarks connected with rivers. The varieties of composition are obvious, and a few rivers are to be found containing but a small quantity of saline constituents and particularly of earthy salts in their waters. In a few cases the composition is given at different localities or at different periods of the year, but generally there is not enough of information to connect these facts with the subject under consideration. Two analyses of the Rhine water at Basle and at Strasburg shew fully 14 parts of Carbonate of Lime and Magnesia in 100,000: again at Bonn in March, 1852, there are fully 10 parts; in March, 1857, only $4\frac{1}{2}$ parts; but in the former case the river was very low and of the usual clearness, in the latter it was much swollen and very turbid. Bischoff has a chapter on mechanical deposits from water, in which he notices various particulars respecting rivers. Of torrents which issue from glaciers, he says, all of them roll along in a turbid grey milky or dark stream according to the nature of the pulverized rock. Generally speaking, in rivers, the quantity of suspended matter increases with the height of the water, and the substances dissolved diminish. The suspended matter consists generally of clay, but in limestone districts it may consist partly or chiefly of carbonate of lime itself. Of course even water containing a considerable quantity of soluble salts of lime may be muddy, but if the mud consist of clay, the mud

* *Cavendish Society's Trans.*, 1854.

will settle readily by repose. If the suspended matter in such waters consist partly or chiefly of carbonate of lime, how it will be affected by the soluble salts present I am not prepared to say, as I have had no opportunity of examining such waters. A French author, whom I shall quote presently, speaks of waters which are never clarified entirely by repose; such are, as he calls them, "*les eaux blanches de Versailles*," which owe their milky tint to their contact with layers of calcareous marl. Whether these waters contain soluble salts of lime or not, I do not know.

In a note to the chapter referred to, Bischoff mentions that Th. Scheerer* had found that "the deposition of suspended matter is hastened when certain salts—alum, sulphates of copper and iron—are dissolved in the water. But since a solution of chloride of sodium behaves like pure water, it cannot be expected that the suspended matter is deposited more quickly in the sea than in rivers." Now here is a mistake, for solution of chloride of sodium does not behave like pure water. Mr. Skey, more correctly, thinks that the transparency of the sea may depend on the precipitation of mud by the saline matter. Scheerer's observations must I think have been too hastily or imperfectly made.

The French works just referred to,† very valuable no doubt for what they were intended, principally engineering, did not, however, contain much of the sort of information I was in search of. That by Darcy gave me some worth noticing. It contains accounts of the filtering operations at Chelsea, Southwark, Thames Ditton, York, Hull, Paisley, Glasgow and Marseilles, also of the natural filters of Nottingham, Perth, Toulouse and Lyons. The natural filters are out of the range of the present enquiry, the first four appear to be on a similar plan to those at Palta, the latter three are different in their arrangements for cleaning the sand. Those of Gorbals, Glasgow, are not sufficiently well described, those of Paisley are; in both the clearing is effected by passing the water from below upwards, but, as the nature of the water is not at all likely to have any analogy with the water under consideration, I need not notice them. The filters at Marseilles, however, are worthy of a little attention. The water which supplies Marseilles is derived from the Durance. This water, as well as that of the Rhone, judging from the description, must have a considerable similarity to that of the Hugli during the rains, at least during certain periods, requiring a long time to settle and become clear. From some things stated in the account of the filtering operations, however, I do not think that the particles of the sus-

* In Poggendorff's *Annalen*, Vol. 82, p 419, date unknown but previous to 1854.

† *Traité de la conduite et la distribution des eaux*, par J Dupuit, Paris, 1854 and *Les Fontaines publiques de la ville de Dijon* par Henry Darcy, Paris, 1856, both beautifully illustrated by plates. For inspection of these I have to thank Dr. Tonnerre, Health Officer to the Municipality.

pended mud can be so very fine as those of the water of the Hugli during the rainy season. There are unfortunately no analyses, but as they come from Alpine regions they must be often diluted with much pure water from melted snow.

The whole thickness of the bed of filtering materials is only .8 metre or about 2 feet 8 inches, of which the upper layer is .3 metre or about 12 inches, consisting of very fine sand (*Sable très fin de Montredon*), below which are layers of middling and coarse sand, gravel and broken stones. It is stated that the filters might work more than eight or ten days, but if kept going longer they would be more difficult to clean. This cleaning is effected by passing the water backwards and upwards through the sand, the impure water being carried off from the surface by channels for the purpose. I have to observe that here we have filter beds much thinner than those at Palta, very fine sand and upward charging, all points that have been considered objectionable for the Palta filters. The cleaning by upward charging requires considerable velocity of current and a continuance of it for four or five hours of time. I have calculated from the data given that it would require about 14 or 15 feet of perpendicular height of water, that is, about as much water as one of the filter tanks, emptied of its filtering materials, would hold two and a half times. No account is given as to how it is done, but I concluded that the level of the canal from which the water is supplied to the filters must be sufficiently high for the purpose.*

I can also bring confirmatory evidence of another kind from English waters, evidence to shew why these waters are not attended with such difficulties in their filtration. There are no circumstances to produce such muddy waters as are to be found even on the European continent, no Alps and glaciers to produce this muddy water even at its source, no mountain snows to melt, and no large falls of rain concentrated in one period. I refer to a paper by Dr. Frankland† on the water supply of the Metropolis during the year 1865-66. In this paper there are several tables of the principal constituents of the water of nine Water Companies for every month of the year. These tables shew that the amount of saline constituents varies during the year, but never to near such an extent as that of the Hugli: they also shew that the earthy salts vary in their amount as indicated by the hardness, but never become reduced to nearly the same degree as those of the Hugli, being at their lowest indeed nearly as much in amount as those of the Hugli in December or January. The variation of course depends upon the rainfall, but this does not vary as respects either quantity or time in the same

* I have since been informed by Dr. Tonnerre that the level of the canal is high above the town.

† Journ. Chemical Society, 1866, Vol. XIX, p. 239.

way as it does in the valley and the source of the Ganges ; in England the rainfall and hardness both rise and fall repeatedly during the year. The case is entirely different from the state of matters here in which we have a very soft water from the commencement of the regular rains gradually becoming harder in November and December and continuing so till the rains set in again in the following year. There is no reason, therefore, to expect any noticeable disturbance in the conditions of filtration in England from change in the condition or nature of the water, but every reason to expect it here, if we can only suppose or admit that such a change in the water *may* affect the filtration. And I would ask, why we should not admit that it should do so? My experience convinced me that it did so affect the filtration, and though I could not satisfactorily account for it or explain how it did so, I continued firmly to maintain that it did so, that this was the true cause of the difficulties, and that consequently other explanations were fallacious and baseless.

I should have been glad to have found other corroborative evidence of the correctness of my opinions, but had no means of obtaining it. Fortunately the discovery of the nature of the peculiarity rendered this of comparatively small importance. I return now to the consideration of this subject a little more in detail.

IV.—After ascertaining that such a very small quantity of lime salts or rather of chloride of calcium, for that was the salt experimented with at first, was sufficient for the purpose required, I proceeded to compare the efficiency of different neutral salts. For this purpose I had to choose a standard of comparison, and as the enquiry related at present to the Hugli water, I chose it with reference to the composition of this. Chloride of Sodium or common salt might have been taken, but I found its effect comparatively so small that I gave that up. The really influential constituents in the river water were the salts of lime and magnesia, particularly the carbonates, and as I found that these were of nearly equal power, I decided to take that which existed in largest quantity, namely carbonate of lime, as the standard of comparison. But as a solution of carbonate of lime in excess of carbonic acid is troublesome to prepare, its strength somewhat troublesome to ascertain, the solution itself weak, consequently involving the addition of a notable quantity of water, besides being liable to change, I chose for my working standard a solution of chloride of calcium equivalent in strength to 1 grain carbonate of lime in 50 cubic centimetres of solution, equal to 1.11 gm. chloride of calcium in 50 c. c. This formed a convenient strength for measuring by a pipette. For the composition of the water, I assumed that during the rainy season it contained salts of Lime and Magnesia equivalent altogether to 7 grains of carbonate of lime in 100,000 flgn. or .07 gramme in 1 litre. This is equal to 4.9 grains in 1 gallon. Perhaps it is rather too

low an estimate, 8 grains or even 9 grains to 100,000 being possibly more correct.

A question soon arose as to what was the general nature of the action, for on that I must regulate the plan on which I was to compare different substances. I have quoted Professor Jevons's electrical theory about the coagulation of clay, which is too speculative for practical application,—also Mr. Skey's, that these precipitating substances must act solely from their affinity for water, because the powerful affinities of the component parts of most of these substances precluded the idea of their decomposition. The general tendency of the experiments I made at first, however, led me to reject this explanation, and to conclude that the action was most probably a chemical one, though it might be difficult, or at present impossible, to explain exactly how it operated. In consequence of this I decided to compare, not absolute weights of the different substances, but their chemical equivalents. Reasons for this conclusion will be given presently.

I generally operated on half a litre of water. This was mixed with the substance to be tried and allowed to stand from 24 to 48 hours. A row of such bottles with different substances was placed on the table with one bottle containing unmixed water, and comparison was made of their respective appearances at the end of a certain time, sometimes of two or three times, and the result noted. Different proportions of the same substance were compared in the same way. The conclusions were drawn only from the experiments made on the same water at the same time, not between different samples of water or between observations made at different times.

The substances compared were chiefly, but not exclusively, those found in natural waters. They may be divided into the following classes:—

Alkalies and alkaline earths.

Acids, or Hydrogen salts.

Neutral salts of the alkalies.

Salts of Lime and Magnesia,—or of alkaline earths generally.

Salts of protoxides of heavy metals, namely of Iron, Manganese and [Copper.

Salts of the sesquioxides,—namely of Aluminum and of Iron.

The range might have been considerably extended, and the series have been more complete, but I could not spare the time necessary for a more numerous series; besides, the river water began to improve about the end of August and continued to do so, as the rains ceased early. The experiments, however, were sufficiently numerous to enable me to draw conclusions of interest.

I shall arrange the substances tried in a tabular form, attaching to them numbers indicating the number of chemical equivalents necessary to produce the same effect as Carbonate of Lime in solution in carbonic acid water. The

equivalents will be in relation to the atomic weight of chlorine 35·5; thus,—combined with Sodium 23, Calcium 20, Iron (Ferrosium) 28, (Ferricum) 18·66, forming Sodium Chloride 58·5, Calcium Chloride 55·5, Ferrous Chloride 63·5, Ferric Chloride 54·16, so that equivalents can easily be converted into absolute weights by multiplying by these numbers, and to facilitate this the equivalent numbers are given. The absolute weights are also given in the last column which, it will be observed, are the products of the two first multiplied by 2 to bring them to the standard of Carbonate of Lime taken as 100, the double of its equivalent. The equivalents and absolute weights, also, are all for the substances free from water of combination, crystallization or solution.

Table of approximate quantities required to produce an equal effect in clarifying the muddy water :—

	Chemical equivalent.	Number of equivalents.	Absolute weight.
Chloride of Sodium or Common Salt,	58·5	40·0	4680
Potassa Hydrate,	56·0	5·0	560
Soda Bicarbonate,	84·0	4·0	672
Acetic Acid,	60·0	3·0	360
Sulphuric Acid,	49·0	2·0	196
Calcium Chloride, or Muriate of Lime, ...	55·5	2·0	222
Magnesium Chloride, or Muriate of Magnesia,	45·5	2·0	182
Nitric Acid,	63·0	1·5	189
Barium Chloride,	104·0	1·0	208
Carbonate of Lime, dissolved by Carbonic Acid,	50·0	1·0	100
Carbonate of Magnesia, dissolved by Carbonic Acid,	42·0	1·0	84
Sulphate of Lime,	68·0	1·0	136
Sulphate of Manganese,	75·5	·5	75·5
Sulphate of Copper,	79·5	·2	31·8
Protosulphate of Iron,	76·0	·15	22·8
Protocarbonate of Iron, dissolved by Carbonic Acid,	58·0	·15	17·4
Alum,	79·2	·05	7·92
Aluminum Chloride, ..	44·8	·05	4·48
Perechloride of Iron,	54·7	·025	2·74

Chloride of Potassium or Muriate of Potassa, Sulphate of Potassa, Acetate of Potassa and Phosphate of Soda were about equally efficacious with common salt.

This table shews the very great difference in efficiency between different substances, common salt having only one-fortieth part of the power of the standard Carbonate of Lime when chemical equivalents are compared, or about one-forty-seventh part when actual weights are compared. On the other hand, Perchloride of Iron is forty times as powerful as Carbonate of Lime, chemical equivalents being compared, or about thirty-six times when actual weights are taken.

A glance at the table will shew that the precipitating power is just in proportion to the facility with which the acid and basic constituent of the salt can separate. The alkalis and alkaline earths ought to be excluded as they exert a chemical change in the soluble constituents of the waters, but it appears to me pretty evident that both the acid and basic constituents of the remainder of these substances take part in the effect produced on the clay. Acids themselves do so, as shewn by the table, even so very weak a one as Carbonic acid gas does so when passed for sometime through the muddy water, as I found from direct experiment. And I also found that when using these small quantities of alumina, the addition of a proportion of potash, more or less, to neutralize the acid constituent of the salt was no improvement but the reverse. Pieces of sheet iron, immersed in a bottle of muddy water and shaken occasionally, in a few hours caused the mud to precipitate very well; the iron evidently had been acted on by the Carbonic acid in the water and the atmospheric oxygen to form a small quantity of a salt of iron which produced the effect.

The numbers in the table are by no means to be taken as accurately ascertained. The shortness of the period during which muddy water of nearly similar quality was available rendered this impossible. After the end of August, I employed water from the river mixed in a vessel with the mud deposited from previous water and stirred up, which can scarcely be taken as a very good representative of the water during the worst period of the rains, though probably good enough for the purpose, as the comparisons between different substances were always made with the same water. But as the month of August was chiefly occupied with experiments on the natural constituents of the water, namely alkaline and earthy salts, and those on the effects of the salts of the heavy metals and of the sesquioxides were not made till September when the water had undergone some change, the numbers given for these latter are not quite so certain, possibly may be stated as smaller than they would have been had the August water been used. The decision on this point must be reserved for next rainy season.

It may be well also to state the absolute quantities of these or at least of some of these substances that would be necessary to clarify a given quantity of the muddy water, calculated from the data given. For this purpose the standard will be Carbonate of Lime, dissolved by Carbonic acid, in the

proportion of .07 gramme to 1 litre or 1000 cub. centimetres or 7 pounds to 100,000 pounds of water, which is equal to 700 pounds to 10 million pounds of water or to 1 million gallons. From this the quantity of any other of the substances given in the table may be calculated from the last column by simple proportion. Thus as 160 Carbonate of Lime is to 700 pounds required, so is 136 Sulphate of Lime to 952 pounds required, or 2.74 Perchloride of Iron to 19.18 pounds required for 1 million gallons of the muddy water of the Hugli.

It is necessary to remember, however, that the table given refers to the dry substances, which is the natural condition in which they are usually found in only a few of the substances enumerated in the table, such as Common Salt and Carbonate of Lime. Most of the other substances contain water of crystallization or water of solution, which last may be a very variable quantity. In the latter case the quantity of dry matter in solution must be known. The following table includes a few of the preceding substances most likely to be of practical application :—

Table of absolute quantities of substances necessary for the clarification of 1 million gallons of muddy water of the Hugli during the rainy season, calculated from the data given above.

	Pounds.
Common Salt, dry, equiv. 58.5,	32,760
Chloride of Calcium or Muriate of Lime, fused or dry, eq. 55.5, ..	1554
Carbonate of Lime, dry, eq. 50,	700
Gypsum or native cryst. Sulphate of Lime, eq. 86,	1204
Sulphate of Iron cryst., eq. 139,	159.6
Alum cryst., eq. 151.2,	55.4
Perchloride of Iron, dry, 54.7	19.15

It may be also worth noting the proportion of a few of these substances to the water, on the above data.

Common Salt,.....	1 to 305
Gypsum,	1 to 8,306
Carbonate of Lime,	1 to 14,286
Perchloride of Iron,*.....	1 to 522,000

These numbers shew that chloride of calcium is nearly twenty-three times as effective as common salt. Skey estimated it as only twice as effective. Schloesing, as will be stated immediately, estimated chloride of potassium as of only one-fifth of the efficacy of lime salts and chloride of sodium

* On referring to my Note Book I find that in July 1866, I had come to the conclusion that about 1 of Perchloride of Iron is sufficient to precipitate the mud from 125,000 of water by standing over night, an approximation at least to the small quantity I have recently found to be sufficient. This was when I was not thinking of its application on the large scale nor searching for a minimum.

weaker still. It will be observed that my numbers differ widely from theirs. The differences are to be accounted for, partly from the circumstance that my examinations have been pushed further than theirs, thus shewing that one lime salt is twice as efficacious as another, that some other salts are far more powerful than lime salts, and that the salts of the heavy metals and particularly of the sesquioxides seem to act on the same principle, which does not appear to have been suspected by either Skey or Schloesing, at least is not alluded to. It is also probably partly due to the differences of the mud operated on, both as respects the composition of the insoluble matter it chiefly consists of, as well as of the soluble matter that it may contain.

V.—I had written thus far when I had an opportunity of seeing Schloesing's paper in the original, in the *Comptes Rendus*, and found it much more complete and interesting than I could have concluded from the brief abstract in the *Chemical News*. He was first led to notice the peculiarity from a circumstance I have mentioned before, namely the treatment of argillaceous soils with distilled water. He not only mentions that distilled water rendered muddy by a mixture of purified fat clay is precipitated by 1-1,000th part of lime salts immediately, but that this is the case also by 1-5,000th part in some minutes and by 1-50,000th part in two or three days. He refers to the muddy water of the Seine becoming limpid in an hour or two by a very small addition of a lime salt, but at the same time states that the Seine water contains 89 milligrammes of lime per litre, equal to 8·9 parts in 100,000 or 15·9 of Carbonate of Lime, a much larger quantity than that which exists in the Hugli water during the rainy season, indeed nearly as much as is found in December and January. Schloesing further directs attention to the influence of this peculiarity on clay soils and on what is called the mechanical analysis of soils; and he further notices the precipitation of mud so carried in rivers by the water of the sea, and also the practical applications suggested by it for clearing muddy water. Indeed he concludes by a reference to the waters of the Durance employed for supplying Marseilles, tracing the muddiness of such waters to their sudden dilution with large quantities of pure water and suggesting a remedy in the restoration of the water to its normal condition by the addition of lime salts or an admixture of some other water containing abundance of these; in complete accordance with all I have been contending for. Schloesing states that Magnesia salts are about equally efficacious with Lime salts, and that salts of Potash are required in about five times the quantity that lime salts are, and that soda salts are still less active. He refers to no other classes of salts, but speaks of Carbonic acid as producing the same effect, attributing its efficacy to the solution of Carbonate of Lime present in the insoluble state.

This idea had occurred to myself, and that also it might explain the

action of the other stronger acids. I am not prepared at present either to admit or deny this. To settle the point would require experiments to be made in which the sources or causes of doubt should be removed. Though it might be supposed that these acids dissolve a small quantity of the otherwise insoluble carbonate of lime, this does not account satisfactorily for the circumstance that the salts of the sesquioxides of aluminum and iron and even of the protoxides of the heavy metals are so much more efficient than lime salts themselves.

I found in another number of the *Chemical News*, that of 14th May, 1869, an abstract of a "Report of the Netherlands Committee." This committee, evidently, (though particulars are not stated), consisted of a body of scientific men examining the waters of certain rivers with a view to their economical use, the Rhine and Maas being particularly mentioned. So far as I can judge from some particulars mentioned, these waters do not appear to be exactly similar to the muddy water of the Hugli. The committee especially recommend Perchloride of Iron for the purification of such turbid waters, along with Carbonate of Soda, and recommend .032 grains Perchloride of Iron for 1 litre which is equal to 1 part for 31,250. I have given it as 1 to 522,000 and without soda. It is obvious that the question of quantity is very important in the application of this artificial method of clarifying muddy water with a view to economy. The great expense, evident in the application of all proportions known before, was one cause that prevented me from giving the subject much attention, as I had adverted to the use of precipitants as far back as 1867, in my paper in this *Journal*.*

One way and the best of all ways of restoring the proper quantity of Lime salts to such water would be to bring it thoroughly in contact with Carbonate of Lime, provided it contained enough of free Carbonic acid to dissolve a sufficient quantity. But this is very doubtful and not very likely in ordinary waters. Experiment shewed only a small improvement.

Both Skey and Schloesing state that the chief point seems to be that there should be a certain quantity of the precipitating substance in proportion to the water, and that the quantity of clay present does not make much difference, Schloesing remarking even that the limpidity is more perfect when the mud attains a certain proportion, just as I have myself found that the muddy Hugli water settled and cleared better by adding some dry soil to it, this of course from the soluble matters contained in that soil. The general point, however, I had not time to examine, my attention having been given to the Hugli water as it presented itself in nature.

Both Skey and Schloesing also describe the effect produced by the term coagulation, and it seems quite appropriate. The very fine particles coalesce as it were into larger and comparatively flocculent ones.

* Vol. XXXVI, Part II, p. 138.

I was not content with these small experiments but tried the process by clarifying the water first by such small proportions of these precipitants, settling one or two days and then passing through a sand filter, and found it to answer perfectly, the filtration going on easily and rapidly. The apparatus was small, the precipitating vessel holding about 45 gallons, the filter being a Zinc tube of about six inches diameter. There were two filters, one with Palta and one with Magra sand: the Palta sand filtered best as I used as small a quantity as possible of the precipitating substances. I could not try it on a larger scale, as my premises are now no longer on the bank of the river. But there cannot in my opinion be the smallest doubt but that the process would answer admirably on the large scale.

My former experiments, at least in my own judgment, proved that the Hugli water during the rainy season could not be filtered without unusual difficulty, and that arising from a peculiarity in the water which I connected with the peculiar distribution of the rainfall in this country, though I could not then explain the cause:—it was a matter of fact whether it could be explained or not. Plans proposed to overcome this difficulty, supported by experience of water filtration in England, I declared would be useless, because the water was different and English experience therefore not applicable.

One special contrivance, which it was alleged would be effective for the purpose, I had tried, and had given my opinion that it was worthless for the purpose. The best plan for filtering the water of the rainy season as it presents itself in nature, I concluded, would be by the use of the Palta sand, properly managed, which includes a proper relation between the amount of filtering surface and the quantity of water to be filtered. All of these statements and opinions I still adhere to, as they were conclusions drawn from the observation of facts, the highest and only true authority from which scientific conclusions can be drawn.

A new idea has supplied me with the means of explaining the nature of the peculiarity, and that not by superseding but by confirming the correctness of my previous conclusions that it was connected with the tropical rainfall, and that was by producing extreme dilution of the water. It also indicated a way to remedy the difficulty of settling and filtering the water. The evidence has been given in the preceding pages, and is founded also on the authority of experimental facts open to scrutiny and criticism. The conclusions, it appears to me, may be of value not only with reference to the Calcutta water supply, but to the purification of water in cases where the circumstances are similar, occurring more generally in tropical countries, but even occasionally in other localities.
